THE FLOW AND FRACTURE OF CRACKED ICE: EXPERIMENTS TO AID MODELING

Dr. Erland M. Schulson
Thayer School of Engineering
Dartmouth College
Hanover, NH 03755
erland.schulson@dartmouth.edu
Voice: 603-646-2888 Fax: 603-646-3856
Award No. N00014-97-1-0211

LONG TERM GOALS

To understand and model the formation of oriented leads in sheets of first-year sea ice with the ultimate goal of contributing to the next generation sea ice model.

OBJECTIVES

The hypothesis is that leads within high-latitude sea ice covers develop from the growth and interaction under far-field compression of pre-existing flaws, such as thermal cracks and re-frozen leads. With this in mind, the near-term objective is to understand the flow and fracture of columnar sea ice containing flaws.

APPROACH

To this end, deformation experiments on the intermediate scale are underway in the laboratory. A study is being made of meter-sized blocks of ice grown under natural conditions. The material is characterized by columnar grains whose crystallographic c-axes are randomly oriented within the plane of the sheet, as in natural covers of first-year sea ice. The blocks are designed to contain an array of pre-existing crack-like flaws, and are being loaded under compression at controlled strain rates. The experiments are being performed using a novel loading frame.

ACCOMPLISHMENTS

The study was initiated during FY97. The loading facility has now been installed, in a sea-ice pond located at USA- CRREL. It is capable of delivering 400 MN at a displacement rate of up to 1 mm/s. This allows blocks as large as 1x1x0.3 m to be deformed on either side of the ductile-brittle transition. As a prelude to the in-pond tests, preliminary experiments were performed in Dartmouth's Ice Research Laboratory using a true multiaxial loading system, to obtain some insight into the role of both boundary conditions and flaws on the compressive failure crack pattern.

SCIENTIFIC RESULTS

The experiments were performed on plates (150 x150 x 25 mm) of columnar saline ice grown in the laboratory, under conditions simulating Nature. They showed that

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 1997**	2. REPORT TYPE	3. DATES COVERED **00-00-1997 to 00-00-1997**

4. TITLE AND SUBTITLE **The Flow and Fracture of Cracked Ice: Experiments to Aid Modeling**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Dartmouth College,Thayer School of Engineering,Hanover,NH,03755**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT **unclassified**	b ABSTRACT **unclassified**	c THIS PAGE **unclassified**	**Same as Report (SAR)**	**3**	

when the ice is rapidly compressed ($10^{-3}s^{-1}$) across the columns under moderate confinement (as in the field), it collapses via the formation of a shear fault. The fault, we believe, is similar to the leads which form in ice sheets. The new point is that the orientation of the fault/lead depends upon the boundary conditions. Boundaries "free" from confinement generate faults oriented at about 30^o to the direction of the major applied compressive stress. Confining boundaries induce shear stresses whose effect is to change the orientation of the fault to about 45^o to the major applied stress. Expanding boundaries induce shear stresses of the opposite sign whose effect is to change the orientation to about 20^o. The observations are reproducible. They suggest that the orientation of leads in ice covers depends upon the stress state within the ice, provided that similar mechanisms are at play on the small and the large scales.

Flaws also affect the orientation of the fault. From tests on a series of specimens containing a set of 16 randomly oriented flaws (20 mm long), it was found that certain defects become activated before the others. We expect that the active ones are those on which the local effective shear stress (i.e., $t_{eff}= t_a- ms_n$, where t_a is the applied stress resolved onto the "crack" plane, s_n is the applied stress normal to the crack plane and m is a coefficient of friction) is the highest. The cracks lengthen and interact with other flaws, leading eventually to the development of the fault. The set of flaws which participate in the process changes when the directions of major and of minor compressive stress are interchanged, thereby changing the orientation of the fault.

Preliminary though they are, and limited perhaps by the size of the test pieces, the results signify that both boundary conditions and pre-existing stress concentrators are important factors in the development of failure zones and large fractures within columnar saline ice moderately confined and rapidly loaded under compression.

IMPACT FOR SCIENCE

The results are beginning to impact the development of the numerical modeling of the flow and fracture of anisotropic sea ice and of lead formation. One paper on the subject is in press, entitled: iOn Modeling Sea Ice Fracture and Flow ......" 1997, W.D. Hibler III and E.M. Schulson, Annals of Glaciology. A new manuscript is in preparation, entitled: "On Modeling the Anisotropic Failure and Flow of Flawed Sea Ice", W.D. Hibler III and E.M. Schulson.

RELATED PROJECTS

This study is closely related to a concurrent investigation (grant no. N00014-97-1-0381) on the numerical modeling of the fracture and flow of anisotropic (cracked) sea ice, by W.D. Hibler III of Dartmouth College.

PUBLICATIONS:

Ductile Compressive Failure of Columnar Saline Ice Under Triaxial Loadingi, J.S. Melton and E. M. Schulson, J. Geophysical Res.-Oceans (submitted).

On Modeling Sea Ice Fracture and Flow in Numerical Investigations of Climatei, W.D. Hibler III and E. M. Schulson, 1997, Annals of Glaciology (in press).

Brittle Failure of Columnar Saline Ice Under Triaxial Compressioni, E.T. Gratz and E.M. Schulson, 1997, J. Geophysical Res., vol. 102, pp. 5091-5107.

The Brittle Failure of Ice Under Compressioni, E.M. Schulson, 1997, J. of Physical Chemistry B, vol. 101, pp. 6254-6258.

The Ductile Deformation of Columnar (S2) Saline Ice Under Triaxial Compression,i J.S. Melton and EM Schulson, 1997, Proc. ISOPE-97, Honolulu, Hawaii, vol. 2, pp. 402-409.

Mechanisms of the Brittle Compressive Failure of Icei, Schulson, E.M., in TMS Annual Meeting, Recent Advances in Fracture, The Minerals, Metals & Materials Society, 1997, edited by A.B.G. R. K. Mahidhara, P. Matic and K. Sadananda, pp. 39-50, Feb. 10-13, 1997, in Orlando, Florida.